DTU Library

Recent Advances in Compressed Air Energy Storage and Thermo-Mechanical Electricity Storage Technologies

Elmegaard, Brian

Publication date:
2013

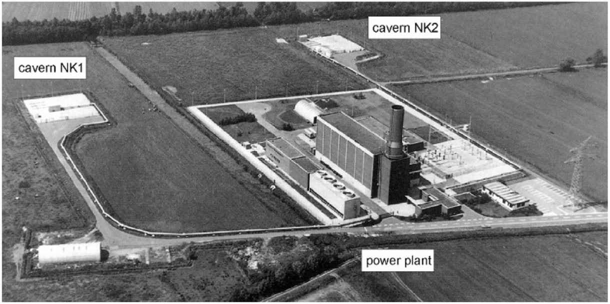
Recent Advances in Compressed Air Energy Storage and Thermo-Mechanical Electricity Storage Technologies

Brian Elmegaard

DTU International Energy Conference, 10-12 September 2013

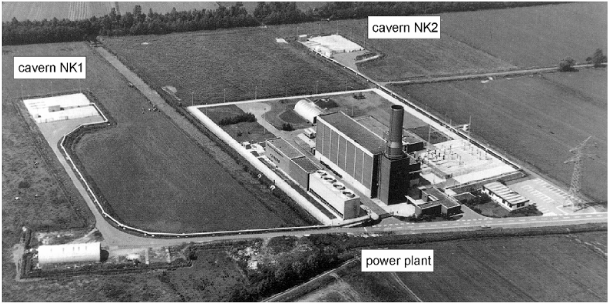
DTU – Technical University of Denmark
Department of Mechanical Engineering
Section Thermal Energy

CAES - operating storage technology



"Huntorf CAES: More than 20 Years of Successful Operation" (Crotogino, Mohmeyer, Scharf) 2001

CAES - operating storage technology



"Huntorf CAES: More than 20 Years of Successful Operation" (Crotogino, Mohmeyer, Scharf) 2001

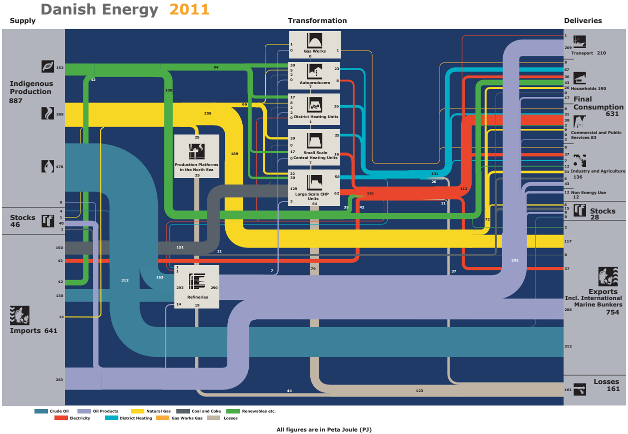
Potential of electricity storage

New ideas and concepts related to CAES

Danish Energy System

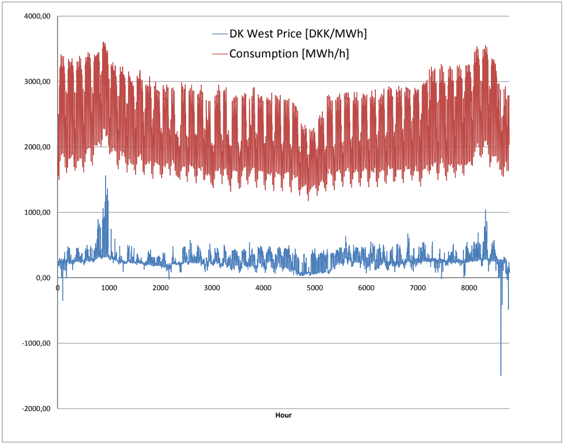
- High share of combined heat and power
- Wind share 4% of energy consumption (28% of electricity)
- Fluctuating wind power is a challenge to power grid and plant control
- Demand-responding consumers are needed (electric boilers, heat pumps, freezing houses, storage. . .)

Danish Energy System



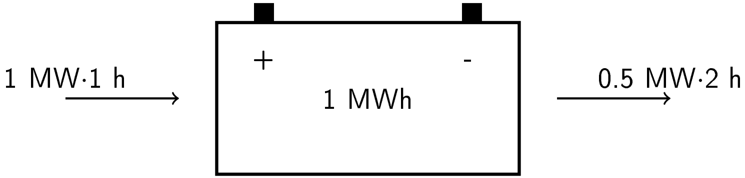
(http://www.ens.dk)

The Electricity Market



2012 Market data from (`http://www.energinet.dk`)

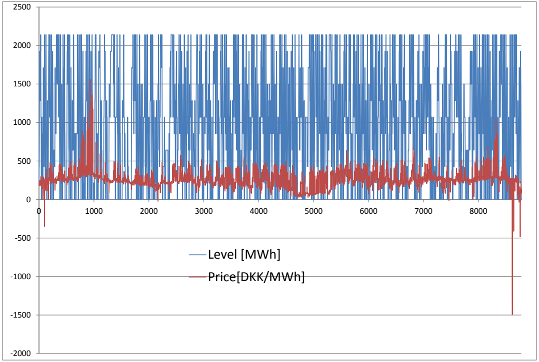
Reversible electricity storage



Case study:
Charging 214 MW
Storage 10 h charging
100% efficiency

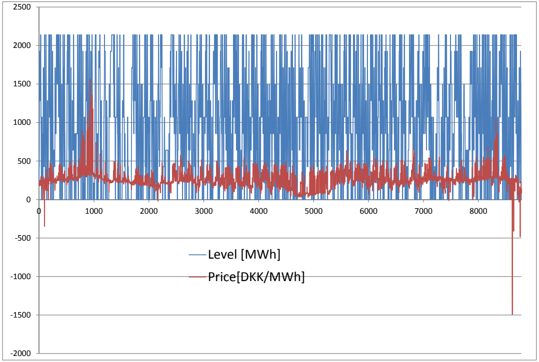
Potential of Reversible electricity storage

Charging 214 MW, Storage 10 h charging, 100% efficiency



Potential of Reversible electricity storage

Charging 214 MW, Storage 10 h charging, 100% efficiency

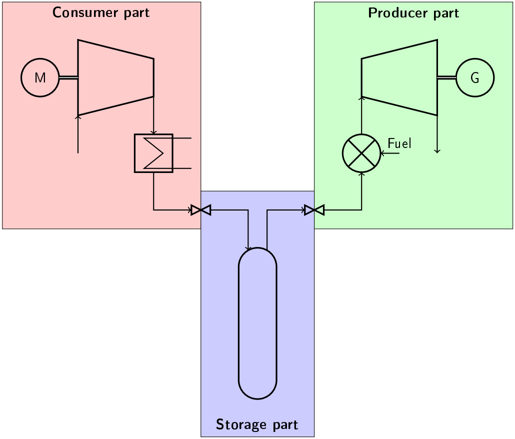


Optimal Net income 77 MDKK

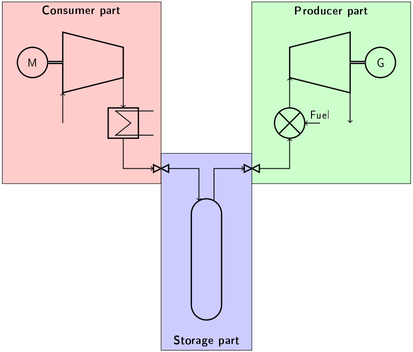
Electricity Storage Technologies

- In operation for bulk storage
  - Pumped hydro storage (PHS)
  - Compressed Air Energy Storage (CAES)
- Under consideration
  - Batteries
  - Flow batteries
  - Flywheels
  - Super conducting magnetic energy storage (SMES)
  - Hydrogen/fuel cells
- System integration possibilities
  - Demand response (Controlling consumption)
  - Heat pumps
  - Electric vehicles
- Fuel storage: e.g., Coal bunkers

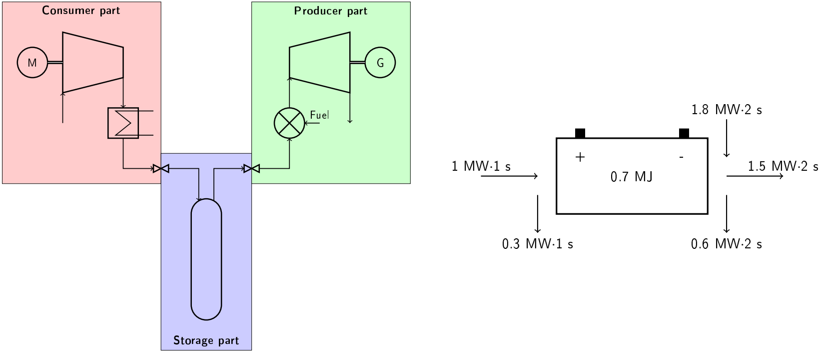
Conventional CAES Process (Diabatic)



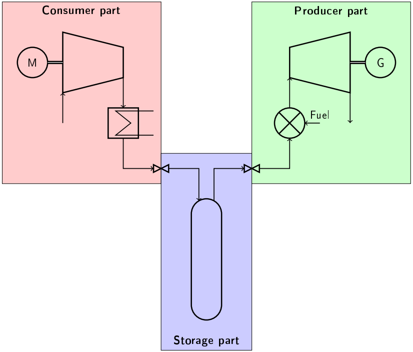
Conventional CAES battery analogy

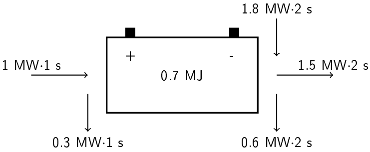


Conventional CAES battery analogy



Conventional CAES battery analogy





Conventional CAES is:
a battery with significant loss during charging and discharging and large consumption during production

Existing and proposed CAES plants

- Huntorf CAES power station (1978) 290 MW production, app. 60 MW charging
- Alabama Electric Cooperative's CAES plant (1991) 110 MW production, app. 50 MW charging
- Norton CAES plant in Ohio (planned) 2700 MW production, flexible charging
- Gaelectric CAES plant in Larne, Northern Ireland (planned) 135 MW production, 80 MW charging

Efficiency definition

- Two inputs at different time: Electricity and fuel
  One output: Electricity

Efficiency definition

- Two inputs at different time: Electricity and fuel
  One output: Electricity
- How should efficiency be calculated? – by exergy

Efficiency definition

- Two inputs at different time: Electricity and fuel
  One output: Electricity
- How should efficiency be calculated? – by exergy
- Exergy is a generalization of high quality energy forms including electricity

Efficiency definition

- Two inputs at different time: Electricity and fuel
  One output: Electricity
- How should efficiency be calculated? – by exergy
- Exergy is a generalization of high quality energy forms including electricity
- Only exergetic efficiency is reasonable

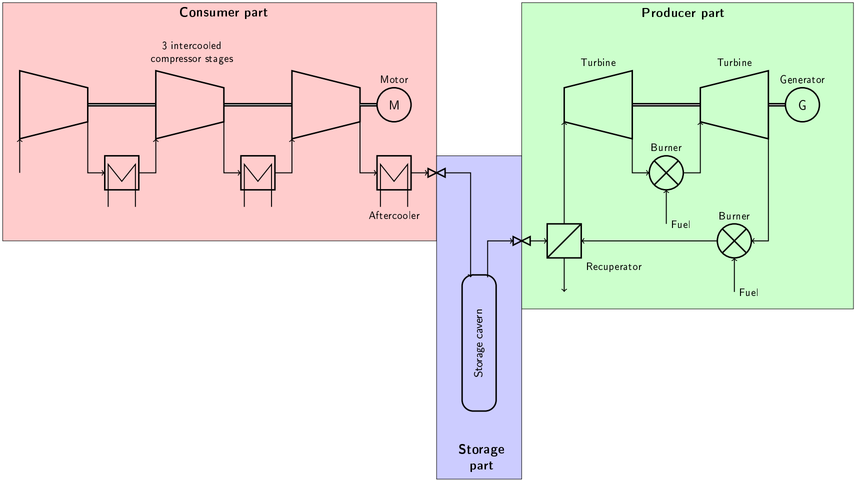
Efficiency definition

- Two inputs at different time: Electricity and fuel
  One output: Electricity
- How should efficiency be calculated? – by exergy
- Exergy is a generalization of high quality energy forms including electricity
- Only exergetic efficiency is reasonable
- Product of component exergetic efficiency $\eta_{\mathrm{sc}} = \eta_{x,\mathrm{c}}\eta_{x,\mathrm{stor}}\eta_{x,\mathrm{t}}$
  Compressor $\eta_{x,\mathrm{c}} = \frac{\Delta E_{air}}{W_c}$
  Storage $\eta_{x,\mathrm{stor}} = \frac{E_{stor,out}}{E_{stor,in}}$
  Turbine $\eta_{x,\mathrm{t}} = \frac{W_t}{\Delta E_{gas}+E_f+E_{ex}} = \frac{W_t}{E_{stor,out}+E_f}$

Efficiency definition

- Two inputs at different time: Electricity and fuel
  One output: Electricity
- How should efficiency be calculated? – by exergy
- Exergy is a generalization of high quality energy forms including electricity
- Only exergetic efficiency is reasonable
- Product of component exergetic efficiency $\eta_{\mathrm{sc}} = \eta_{x,\mathrm{c}}\eta_{x,\mathrm{stor}}\eta_{x,\mathrm{t}}$
  Compressor $\eta_{x,\mathrm{c}} = \frac{\Delta E_{air}}{W_c}$
  Storage $\eta_{x,\mathrm{stor}} = \frac{E_{stor,out}}{E_{stor,in}}$
  Turbine $\eta_{x,\mathrm{t}} = \frac{W_t}{\Delta E_{gas}+E_f+E_{ex}} = \frac{W_t}{E_{stor,out}+E_f}$
- Other definitions should not be used as storage efficiency:
  For example Gas turbine cycle efficiency,
  Energy output to input ratio

Alstom CAES Process



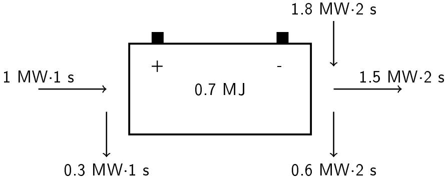
Alstom Performance

	Min. pressure	Max. pressure
Storage Pressure [bar]	50	78
Compressor Power [MW]	45	50
Charging time [h]	42	
Charging Exergetic Efficiency [%]	72	72
Fuel consumption rate [MW]	132	132
Combustion Temperature [°C]	853	853
Turbine Power [MW]	116	116
Discharging time [h]	26	
Discharging Exergetic Efficiency [%]	51	49
Gas turbine efficiency [%]	30	
Plant energy efficiency [%]	56	
Primary energy efficiency [%]	29	
Storage Efficiency [%]	36	

Alstom Exergy Losses

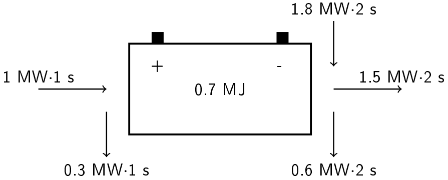
	Exergy loss [MW]	Relative exergy loss [%]
Compressor 1	6.8	2%
Intercooler 1	14.3	5%
Compressor 2	6.8	2%
Intercooler 2	15.4	6%
Compressor 3	7.6	3%
Aftercooler	20.9	8%
Throttling	12.2	4%
Recuperator	22.9	8%
Air turbine	5.8	2%
Combustion 1	124.7	45%
Turbine	14.5	5%
Combustion 2	25.4	9%

Potential of CAES electricity storage



	Charging [MW]	Storage [h]	Efficiency [%]	Income [MDKK]
Reversible	214	10	100	77
Adiabatic	214	10	70	29
Conventional	214	10	40	98

Potential of CAES electricity storage

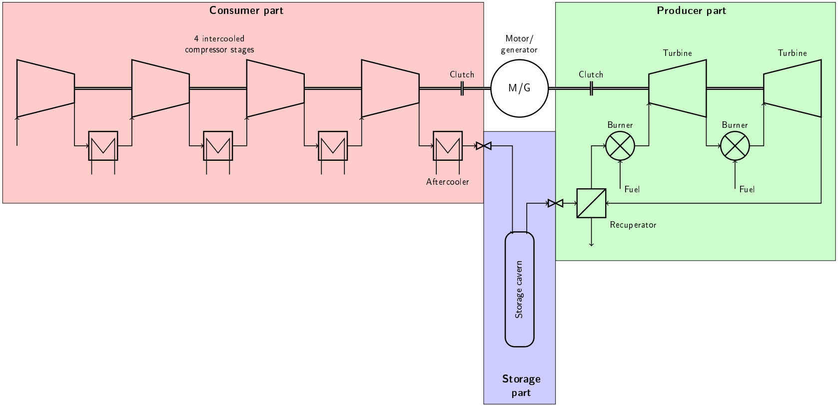


	Charging [MW]	Storage [h]	Efficiency [%]	Income [MDKK]
Reversible	214	10	100	77
Adiabatic	214	10	70	29
Conventional	214	10	40	98

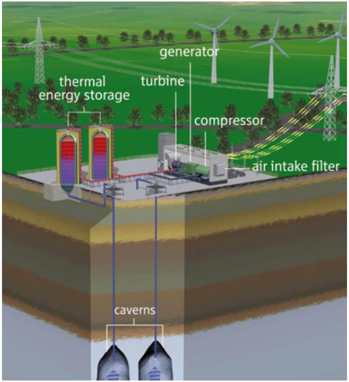
Conventional CAES with gas consumption and low efficiency has better economic potential than adiabatic systems

Investment: ≈1000 MDKK

Alabama CAES Process

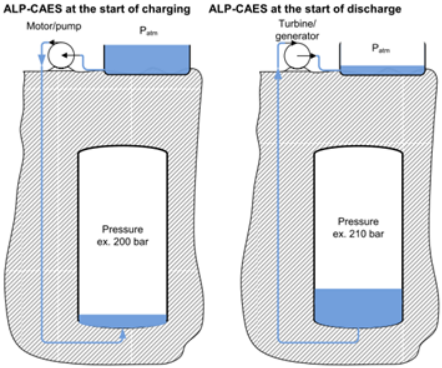


Adiabatic CAES



Adele project www.rwe.com
No fuel consumption, compression heat stored

Liquid Piston CAES



Minimal compression heat

1: CAEstorage, 2: ALP-CAES project

Isothermal CAES

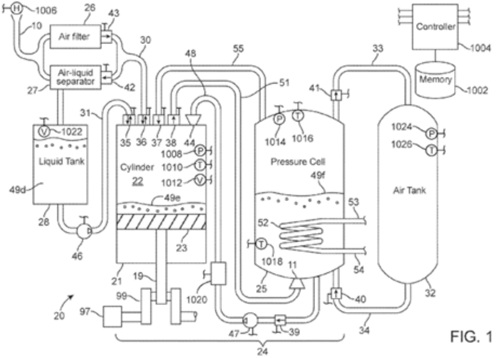


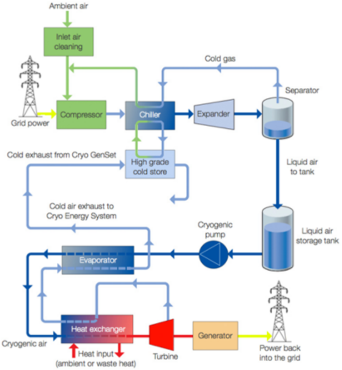
FIG. 1

www.lightsailenergy.com

Liquid (water) used for heat transfer during charging and discharging

1: Lightsail, 2: General Compression, 3: SustainX

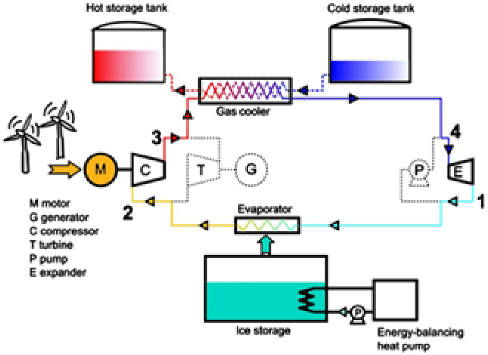
Liquid Air Electricity Storage



www.highview-power.com

Waste heat integration possible, efficiency of liquifaction challenging

Transcritical Carbon Dioxide Cycle



leni.epfl.ch

Transcritical CO_2 cycle with reversible compressor and expander

Water storage

Summary

- Exergetic efficiency should be used as the measure of efficiency of electricity storage

Summary

- Exergetic efficiency should be used as the measure of efficiency of electricity storage
- Conventional (Diabatic) CAES is low-efficiency storage (<40%)

Summary

- Exergetic efficiency should be used as the measure of efficiency of electricity storage
- Conventional (Diabatic) CAES is low-efficiency storage ($<$40%)
- Adiabatic CAES may reach reasonable storage efficiency ($\approx$ 70%)

Summary

- Exergetic efficiency should be used as the measure of efficiency of electricity storage
- Conventional (Diabatic) CAES is low-efficiency storage (<40%)
- Adiabatic CAES may reach reasonable storage efficiency ($\approx$ 70%)
- Conventional CAES has best economic potential

Summary

- Exergetic efficiency should be used as the measure of efficiency of electricity storage
- Conventional (Diabatic) CAES is low-efficiency storage ($<$40%)
- Adiabatic CAES may reach reasonable storage efficiency ($\approx$ 70%)
- Conventional CAES has best economic potential
- Several ideas and concepts are investigated

Summary

- Exergetic efficiency should be used as the measure of efficiency of electricity storage
- Conventional (Diabatic) CAES is low-efficiency storage (<40%)
- Adiabatic CAES may reach reasonable storage efficiency ($\approx$ 70%)
- Conventional CAES has best economic potential
- Several ideas and concepts are investigated
- Bulk electricity storage is needed in the future, and will involve
  - Large investments
  - Significant losses of exergy due to irreversibilities
  - Large volume and/or area
  - Big price fluctuations or high consumer prices to be feasible